Gamma-Ray Large Area Space Telescope

Preliminary

Mission System Specification

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Acronyms

b	bit
B	Byte
CCSDS	Consultative Committee for Space Data Systems
DN	Data Number
DL	Downlink
EU	Engineering Units
FITS	Flexible Image Transport System
Gb	Gigabit
GCN	Gamma Ray Burst Coordinates Network
GLAST	Gamma ray Large Area Space Telescope
GN	Ground Network
GOF	Guest Observer Facility
GPS	Global Positioning System
HEASARC	High Energy Astrophysics Science Archive Research Center
IOC	Instrument Operations Center
MB	Megabyte
MOC	Mission Operations Center
PB	Playback
RT	Real Time
SC	Spacecraft
SI	Science Instrument
SN	Space Network
SOC	Science Operations Center
SSR	Solid State Recorder
TBD	To Be Determined
TBR	To Be Resolved
TDRSS	Tracking and Data Relay Satellite System
UL	Uplink

1 Introduction

1.1 Purpose and Scope

This document responds to the level 1 requirements for the Gamma–ray Large Area Space Telescope (GLAST) mission that will be established in the GLAST Program Plan and to the science requirements that are given in the Science Requirements Document. Implementation of these two sets of requirements is accomplished in this document by defining the operational system that acquires the science data and by specifying the performance characteristics of the different elements of that system. These are the level 2 requirements for the mission that will be approved by the GLAST project. These requirements, in turn, flow down to and provide the framework of top-level requirements that enable the development of specifications for the system elements themselves.

1.2 GLAST Overview

The GLAST mission is a follow–on to the EGRET (Energetic Gamma–Ray Experiment Telescope) on the Compton Gamma Ray Observatory (CGRO). GLAST is a high–energy, gamma–ray Observatory designed to observe celestial gamma–ray sources in the approximate energy range of 20 MeV to greater than 300 GeV. The GLAST field of view of at least 2 steradian is required to make the primary Science Instrument (SI) particularly effective for exploring the transient nature of the high–energy gamma–ray sky. GLAST will address many fundamental astrophysical questions from a diverse population of sources – stellar mass objects, in particular, neutron stars and black holes; the nuclei of active galaxies that likely contain supermassive black holes; interstellar gas in the Galaxy that interacts with high–energy cosmic rays; the diffuse extragalactic background; supernovae that may be sites of cosmic–ray acceleration; and the mysterious gamma–ray bursts.

1.3 System Definition

The operational concepts given in the remainder of this section are the basis for the requirements that are given in section 3. The operational system for GLAST is the end-to-end system that acquires the observational data and produces the scientific data sets. It will be operated as a facility for the science community.

1.3.1 System Architecture

The GLAST system is shown in hierarchical form in the architecture block diagram of Figure 1-1. Basically, the overall system is comprised of 3 segments, the flight segment (everything that flies), the ground segment, and the space-ground communications segment that connects flight and ground segments. This specification is organized along these architectural lines.

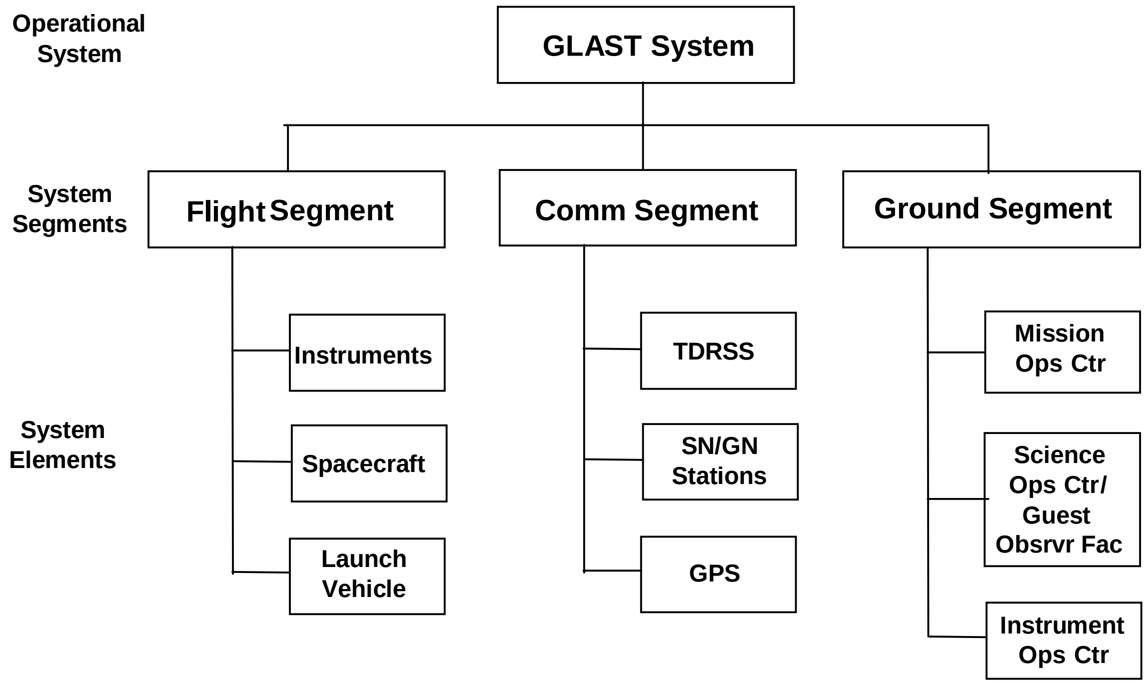

Figure 1-1 Architectural Block Diagram of the GLAST System

1.3.2 Functional Description

A functional configuration of the system is shown below in Figure 1-2. The design of this configuration may be affected by certain connectivities and consolidations that are already in progress and that are scheduled for completion well before the current GLAST launch date in 2005. The most significant developments with respect to GLAST are the following:

1) IP connectivity throughout the NASA ground networks by 2001,
2) Integrated Mission Operations Center (IMOC) at GSFC by 2Q 2001,
3) Scheduling of data services consolidated at White Sands by 3Q 2001, and
4) Level zero processing performed at ground stations by 4Q 2003.

These may cause some functions to shift from one location to another, which will change the functional partitioning between the different operations centers.

Starting at the left of Figure 1-2, the GLAST Observatory appears in low earth orbit, supported by the Global Positioning System (GPS) and two communications systems. The Observatory consists of primary and secondary Instruments and the Spacecraft. In operation the Observatory acquires observational data continuously and stores it on board. During routine operations the data are transmitted to the ground once per day. The GPS supports the Observatory by providing orbit position and time. The Observatory does not require orbit maintenance and control, but it does need orbit determination for contact scheduling and data tagging.

One of the communications systems is a direct link to ground system, using at least 2 ground stations, a primary and an alternate. The other communication system is a relay satellite system, viz., TDRSS. The full-view coverage of the geostationary TDRS relay satellites is used when extended contact times are needed, such as during launch and early orbit, during emergencies, during software uploads, and whenever random access times are needed, such as for gamma-ray burst alerts. For normal operations, however, transmissions of the bulk science data are able to use the intermittent, direct contacts of low latitude ground stations. Two direct link ground stations are shown in the figure to represent the complementary operations of a primary and an alternate station.

The ground segment is comprised of 3 operations centers, a Mission Operations Center (MOC), an Instrument Operations Center (IOC), and a Science Operations Center (SOC), which includes a Guest Observer Facility (GOF). The MOC handles the overall operations of the Observatory including health and safety of the Spacecraft, the monitoring of any critical instrument engineering parameters, the generation of all command loads, and the conduct of contingency operations. The MOC also receives alerts from the Observatory and forwards Gamma-Ray Burst (GRB) alerts to other observatories on the Galactic Coordinates Network (GCN). The IOC handles the operations of the primary instrument, including instrument health and safety, instrument configuration commanding, optimization of instrument detection and operation, and validation of instrument data. A second IOC will be required if a separate secondary instrument is selected by NASA. The SOC performs the observational planning for the mission, performs production data processing of the science data, and archives all mission data. In addition, the SOC coordinates requests for pointed observations from external users and from the observatories on the GCN. The GOF operates as an annex to the SOC in support of guest observer projects. These 3 centers are not constrained to be co-located. High speed communications between all elements of the ground system will support the transfer of large volumes (10s of Gb) of data and provide access to databases in different parts of the system.

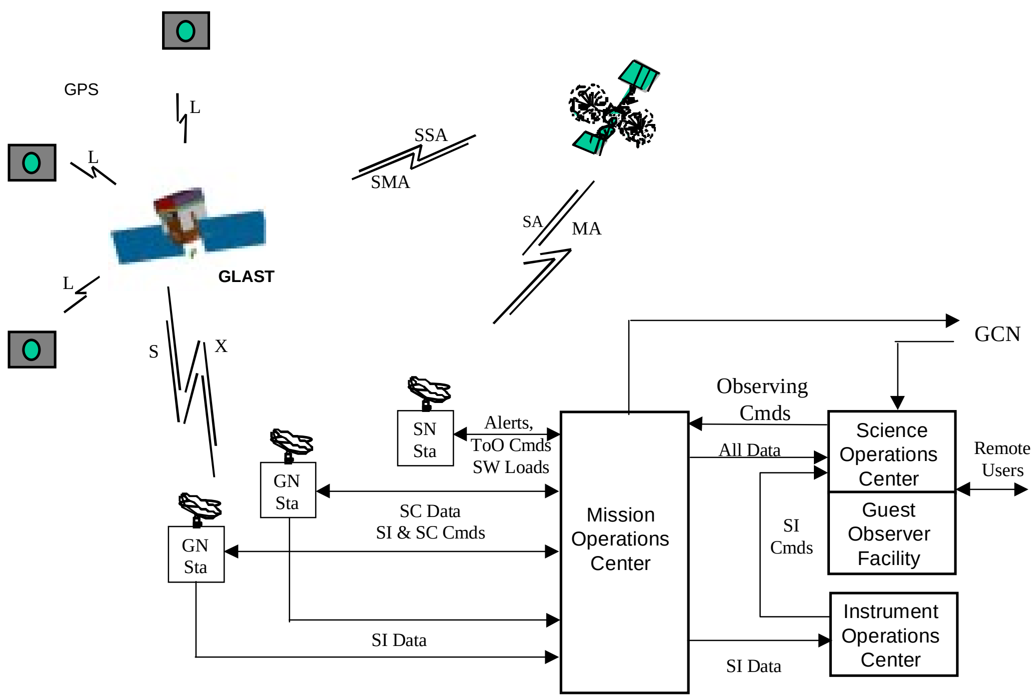

Figure 1-2 System Architecture for GLAST

1.3.3 System Data Flow

In this section the flow of data through the system is described with the aid of the data flow diagram in Figure 1-3. Beginning at the left of the diagram, it is seen that three types of data are generated on board the Observatory, SC engineering data, SI engineering data, and SI science data. Each type of data is encapsulated in its own packet at the source of its generation. The science data packets are distinguished by having a variable length and by being self-contained, needing no other data except calibration data for their subsequent processing on the ground. The fixed length engineering data packets for both SI and SC are designed to support the health and safety monitoring of their respective system. All packets are capable of being stored and transmitted later as playback data or can be transmitted immediately as real time data. Playback data are accumulated in on-board storage over a nominal period of 24 hours and are downlinked directly to a ground network (GN) ground station once per day. There is sufficient on-board storage that a number of orbits may be used to transmit the data without the data being overwritten. In the downlink process the packets for both real time data and playback data are transported via a number of smaller, fixed-length frames.

On the ground, the playback data are captured and buffered at the GN station before further transmission. The data capture process includes demodulation, bit and frame synchronization and error checking. A buffer then holds the data while accounting information is generated and sent to the MOC to schedule additional contacts if necessary for possible retransmissions. The GN buffer is sized to accommodate the maximum amount of data that can be transmitted in a direct contact. An 8 minute contact, for example, at 150 Mbps results in 72 Gb. (This could be science data that was not filtered on board.) Retransmissions of stored data may be performed on subsequent contacts within the same orbit, or on subsequent orbits. The retransmission may consist of either the entire data set, in the case of a missed contact, or of selected packets that incurred uncorrectable errors in the transmission process. Once the transmission is complete at a GN station, the source packets are forwarded to the MOC . In the process of transmission to the MOC the data will be transported by means of other data structures and protocols, but these will be transparent to the user.

A parallel process of capture, packet recovery and transport is used for real time data, but in this case without any delay for retransmissions. The real time data proceed directly to the MOC. Any data with errors are simply discarded.

Since the MOC may receive data from more than one GN station, the data are buffered again while the MOC performs the task of eliminating overlaps, or redundancies, in the packets. When the downlink data set is complete, the form of the data is the same as when it entered on-board storage, a sequenced set of data packets, and the MOC can release the on-board storage to support the next 24-hour period. The MOC will also perform the task of separating the data into different streams for different destinations. SC engineering data are retained in the MOC, while SI engineering data and science data are sent to the IOC. All data are also forwarded to the SOC. The MOC uses the SC engineering data to monitor the health and safety of the SC. It also stores these data locally to perform long term trending evaluations.

In the IOC, the SI engineering data are further separated from the SI data set and sent to the SI health and safety process. The SI science data are used to support assessment of SI performance and configuration logging. The IOC has the same capability as the SOC to process events, calibrate them, and generate photons from them. The IOC will provide support to the SI team in the conduct of its own investigations. In addition there is an emphasis in the IOC on monitoring and assessing instrument performance. Thus the IOC will generate new calibrations as needed and adapt the instrument to the on-orbit measurement task by generating modified detection algorithms. The IOC will maintain a performance model of the SI to support this effort. Modified detection and/or operation algorithms create a need for software uploads that will be sent to the MOC for uplinking.

For diagnostic purposes raw science data can be accommodated in both MOC and IOC by proper sizing of buffers. The MOC buffer, for example, if sized at 98 Gb, will accommodate 1 full orbit (96 min) of raw science data generated at a rate of 17 Mbps. Two GN stations separated by half an orbit could each provide 49 Gb. Such operation can provide a continuous stream of raw data to the extent that contacts can be made on consecutive orbits.

In the SOC, SI science data are first formatted using a standard archive data format and then archived in raw data archives. Subsequently, the data are event processed and calibrated to generate a photon data set, which is also archived. The IOC in support of its assessment of instrument performance may access both of these archives. Finally, the SOC processes the photon data to generate higher level data products, such as sky maps, light curves, energy spectra, source catalogs, and any other product that becomes necessary or desirable. These data are archived on line for access by the users of the GLAST system. During the course of the mission the SOC supports archival research in the same fashion as the HEASARC does after the mission.

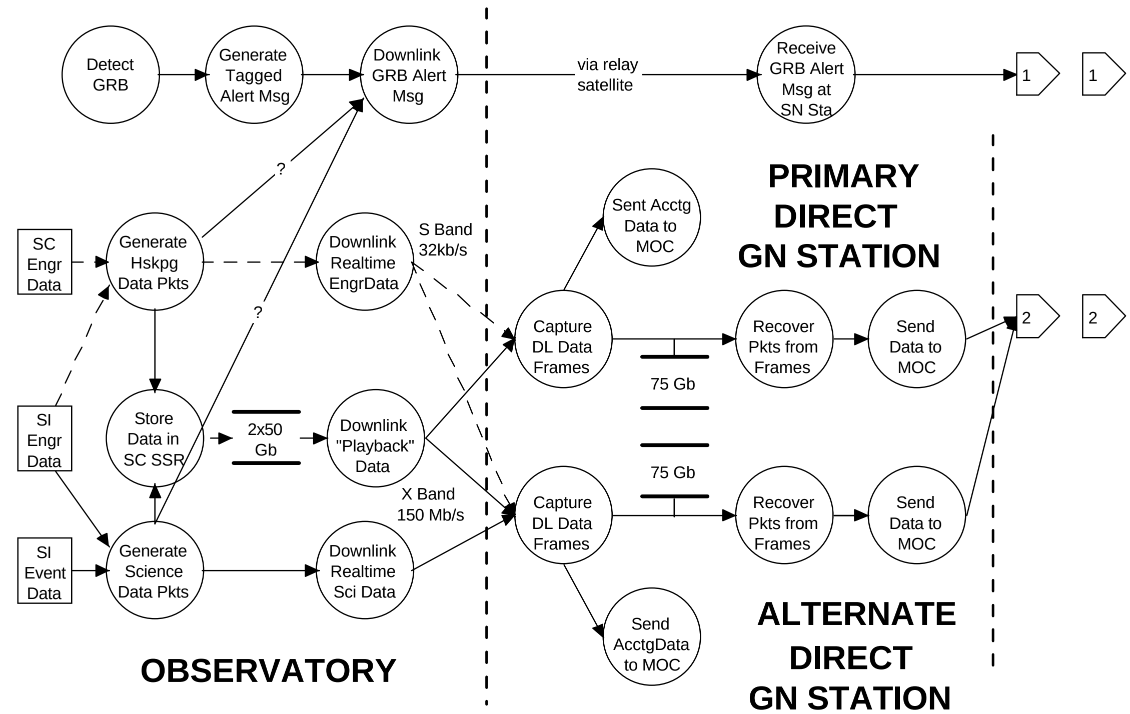

Figure 1-3 System Data Flow Diagram

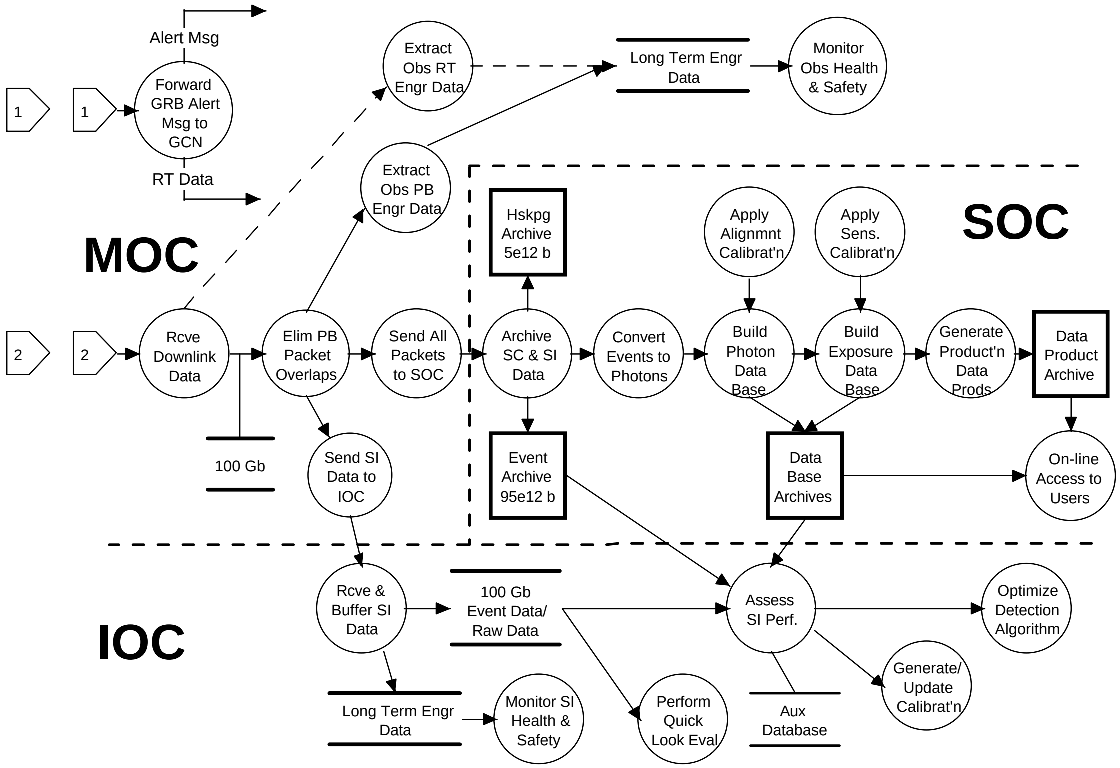

Figure 1-4 System Data Flow Diagram

1.3.4 Modes of Operation

Modes are different ways or methods of accomplishing something. They are usually distinguished by configuration. A state is a particular instance of operation. The GLAST system employs four modes of operation of the Observatory as seen below in Figure 1-4. Transitions between modes are commandable, and it is possible to transition from any mode to any other mode. These commands may be either immediate real-time commands as when the Spacecraft is in contact with the ground, or delayed commands that are stored on board. Some of the transitions may be performed autonomously as well, as will be seen in the discussion below.

Observations are carried out in either the Sky Survey Mode or the Pointed Observation Mode. In the Sky Survey Mode the Observatory is nominally zenith pointed. In this mode there is the capability of a cyclical roll offset that can be incremented every few orbits to point the Observatory above and below the plane of the orbit. This motion, coupled with the wide, 2 sr, field of view of the primary instrument, provides full sky coverage several times per day. The Observatory can run in this mode indefinitely.

In the Pointed Observation Mode the Observatory is commanded to point at a particular target in the sky and to hold on that target for a commanded duration. At the end of the time duration, the Observatory will be commanded to the Sky Survey Mode if another pointed observation command is not pending. Sequences of stored commands may be used to carry out a sequence of pointed observations. These sequences can include alternate targets to be viewed during occultation of the primary target by the Earth.

Transient observations also are performed in the two observing modes. When enabled in the Sky Survey Mode, detection of a GRB on board will cause an autonomous transition to the Pointed Observation Mode. At the same time a GRB alert message will be sent to the ground via relay satellite. The GRB alert message will be followed by real-time data, also via relay satellite, for the period of GRB observation. This period will be a commandable parameter. Upon expiration of the GRB observation time, the Observatory will transition autonomously back to the Sky Survey Mode and will resume sky survey operation. Similarly, a transient observation also may be performed by a ground-generated alert command arriving via relay satellite. Such ground alert commands can carry an observation time of their own, so that there is the capability of over-riding the preset observation time on board. Transient observations also may be performed from the Pointed Observation Mode. When enabled, the current pointed observation may be interrupted by an on-board detected GRB, with autonomous transitions to and from the transient target. Ground alerts can also interrupt an on-going pointed observation. Transient observations are not provided with alternate occultation targets. An occultation of a transient target represents a loss of data for the duration of the occultation.

The Downlink Mode is used to transmit the science data directly to the ground. This mode is not interruptable by transient observations. It is entered and exited by command. Although the acquisition of observational data may not be suspended, the Observatory will be zenith pointed in this mode to allow the gimbaled X-band antenna to track the ground station. Concurrently, the Observatory will transmit its housekeeping data to the ground and will receive any command uploads via the S-band omni antenna.

A Safe Mode is used to protect the Observatory when anomalies are detected. These are faults that are not correctable on board by the Fault Detection and Correction (FDC) capability. In Safe Mode the Observatory is in inertial hold with its attitude referenced by the Sun. Observing is suspended in this mode, as the instruments are powered off. Autonomous transitions to the Safe Mode will occur whenever an anomaly is detected in any of the other modes. A safe mode alert message is generated by the autonomous transition and sent to the ground via relay satellite. Mission Operations then needs to schedule a contact to obtain housekeeping data via S-Band omni and proceed to resolve the anomaly. A ground command is necessary to exit the necessary Safe Mode and resume normal operations.

The SI will have modes of its own. Different data taking modes, such as Normal (filtered data), Raw Data (unfiltered data), and Calibration (unvetoed high-energy cosmic rays) will be transparent to the SC. Others, such as, Off for SAA, and Boot Up from resets, will result in interruption of data flow and the generation of gaps. But since these can occur in any observation mode, the Observatory will simply maintain its pointing mode. Software load from the ground will need to be performed under a pointing constraint in the Pointed Observation Mode to ensure visibility of the relay satellite with the omni antenna. Of course, a data gap would be generated during the load and algorithm changeover.

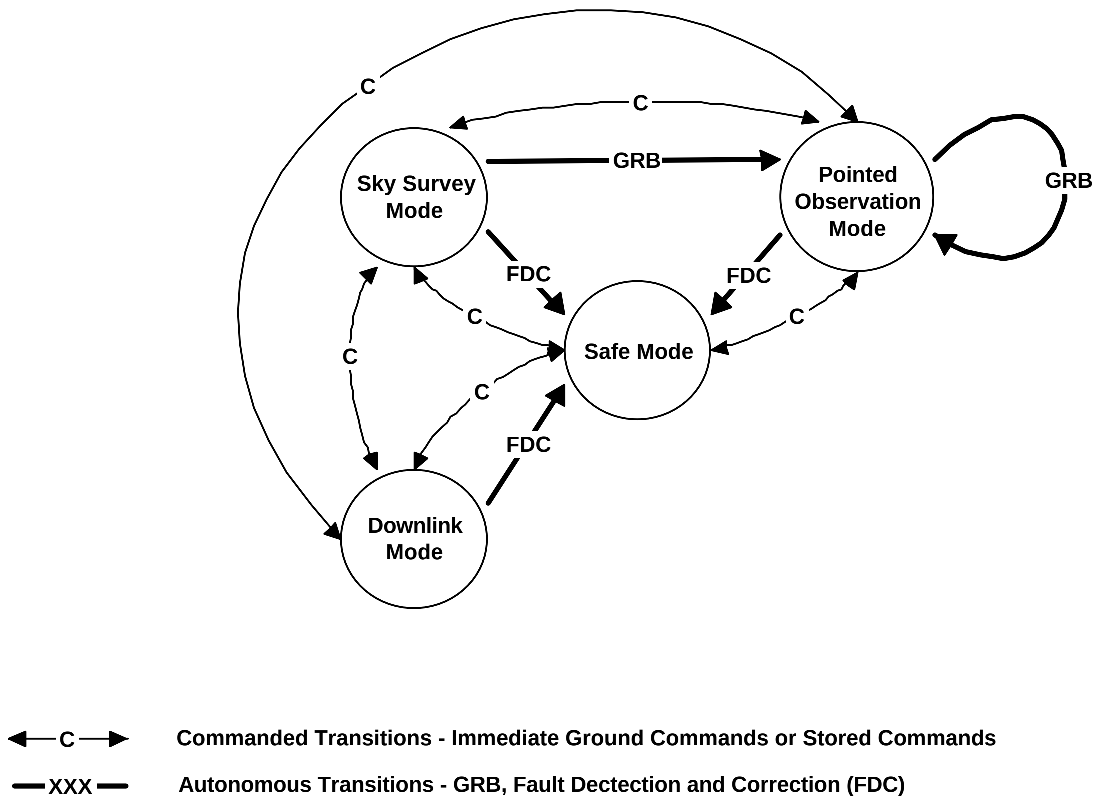

Figure 1-5 Observatory Modes and Transitions

2 Applicable Documents

GLAST Program Plan, TBD

GLAST Science Requirements Document, TBD, 1999

CCSDS 701.0–B–1, "Recommendation for Space Data Systems Standards. Advanced Orbiting Systems, Networks, and Data Links: Architectural Specification." CCSDS Recommendation, Blue Book, October 1989.

CCSDS 102.0–B–3, "Recommendation for Space Data Systems Standards. Packet Telemetry." CCSDS Recommendation, Blue Book, October 1989.

CCSDS 202.0–B–2, "Recommendation for Space Data Systems Standards. Telecommand, Part 2: Data Routing Service." CCSDS Recommendation, Blue Book, October 1989.

NSS 1740.14, NASA Safety Standard, Guidelines and Assessment Procedures for Limiting Orbital Debris, August 1995.

3 GLAST Requirements

3.1 General Requirements

General requirements apply throughout the GLAST system.

3.1.1 Lifetime

The operational lifetime shall be a minimum of 5 years, with a goal of 10 years, following an initial 30 (TBR) day period of in–orbit checkout. The orbital lifetime shall not exceed 25 years beyond the operational lifetime.

3.1.2 Launch Date

The GLAST Observatory will be launched in 2005 (TBR).

3.1.3 Orbit

Orbit parameters for the GLAST mission are given in the following paragraphs.

3.1.3.1 Altitude

The initial orbit altitude shall be 550 km. Subsequently, orbit altitude will be uncontrolled, resulting in a gradual decay during the course of the mission. There is no requirement for orbit maintenance. [Initial altitude is selected to provide a mission life of 10 to 25 years for the Observatory Mass/Area ratio under conditions of plus and minus 2 sigma solar flux estimates for the epoch of the mission.]

3.1.3.2 Inclination

Orbit inclination shall be 28.5 degrees (TBR).

3.1.3.3 Eccentricity

Orbit eccentricity shall be less than 0.001 (TBR). [Eccentricity is selected to maintain the drag altitude within 10 km.]

3.1.4 Serviceability/Retrieval

There is no requirement for in–orbit servicing or Observatory retrieval.

3.1.5 Disposal

At the end of mission life, the method of disposal shall be by uncontrolled reentry into the Earth's atmosphere (TBR). The Observatory shall be designed to not exceed a debri casualty area of 8 m^2.

3.1.6 Coordinate Systems

GLAST shall use the J2000 inertial coordinate system as a standard means of identifying and reporting celestial objects and of communicating pointing directions between its systems.

3.1.7 Communications Standards

The GLAST program shall employ the standard communications format and protocol as recommended by the Consultative Committee on Space Data Systems for the transport of its data within the flight system, the space-ground communication systems and the ground system. Other packet transport protocols will be used in the ground system as well, but these will be transparent to GLAST.

3.1.8 Data Modes

This section defines the data modes for the GLAST system.

3.1.8.1 Observing Data Modes

3.1.8.1.1 Science Data Mode

The GLAST system shall have the capability to handle normally preprocessed data from the primary instrument. These data are generated in the data-taking operational modes of the Observatory at an average data rate of 300 kbps and are stored and forwarded in variable medium-length packets on a daily basis.

3.1.8.1.2 Raw Data Mode

The GLAST system shall have the capability to handle unprocessed raw data from the primary instrument on occasion, as required. Raw data are generated also in the data-taking operational modes of the Observatory at a rate on the order of 15 Mbps and are stored and forwarded in variable large-length packets on an orbital basis.

3.1.8.2 Maintenance Data Modes

3.1.8.2.1 Diagnostic Data Mode

The GLAST system shall have the capability to handle diagnostic data from the primary instrument on occasion, as required. Although raw data may be used for diagnostic purposes, diagnostic data is distinguished by an interruption in normal instrument observational operation and by the requirement to downlink it on an orbital basis. The data itself may consist of memory dumps and self-test data.

3.1.8.2.2 Software Upload Mode

The GLAST system shall have the capability to develop, generate and upload software during the operational lifetime for the primary instrument on occasion, as required. This mode also incurs an interruption in normal instrument observational operation. This mode will be utilized as frequently as a weekly basis early in the mission and thereafter on special occasion to adapt and optimize the instrument to the observing task.

3.1.9 Data Loss

The loss of observational science data due to operational constraints and fault recovery shall not exceed 2.0 % (TBR). The loss of observational science data due to identifiable errors shall not exceed 1.0% (TBR).

3.1.10 Data Quality

The maximum error rate for undetected bit errors in the science data stream shall not exceed 1×10^{-10}.

3.1.11 Data Autonomy

GLAST shall use self-contained packets for its science data. Each packet shall be constructed at its source (the primary instrument) to contain all relevant on-board observatory data for its subsequent processing on the ground. This does not include calibration and alignment data, which are separate data sets.

3.1.12 Data Latency

The maximum overall data latency shall be 48 (TBR) hours. This is allocated as follows:

On board storage	24 – 30 hours
Downlink and transmission to SOC	6 – 12 hours
Production data processing	6 hours

3.1.13 Modes of Operation

The GLAST system, including Observatory, communications systems, the Mission Operations Center, the Instrument Operations Center, and the Science Operations Center, shall support the following Modes of Operation (TBR):

Sky Survey Mode,
Pointed Observation Mode (any direction, any time),
Downlink Mode,
Safe Mode (solar panels sun pointed).

3.1.13.1 Sky Survey Mode

In the Sky Survey Mode, the Observatory shall be zenith pointed with the capability for executing cycles of incremental roll offsets. The size of offset, number of offsets per cycle, and the number of orbits per offset shall be commandable parameters.

3.1.13.2 Pointed Observation Mode

In the Pointed Observation Mode, the Observatory shall reference its pointing to celestial sources. Upon command the Observatory shall point to a celestial target and shall maintain its pointing direction until re-commanded. The target coordinates and its observation time shall be commandable parameters.

3.1.13.3 Downlink Mode

In the Downlink Mode, the Observatory shall be zenith pointed for gimbaled X-band antenna tracking of direct link ground stations. This mode is not interruptible by transient observations.

3.1.13.4 Safe Mode

In the Safe Mode the Observatory shall reference its pointing and control to the Sun. The inertial attitude of the Observatory shall be adjusted to provide thermal and power safe environment. The Observatory shall maintain its safe mode attitude indefinitely, or until commanded to an operational mode by ground command.

3.1.14 Coordination with Other Observatories

GLAST shall transmit alerts to, and post alerts from, other observatories. The GLAST system shall transmit alerts of Gamma-ray Bursts, including time and arrival direction, automatically on the internet within 5 (TBR) seconds 95% of the time.

3.1.15 Autonomy

GLAST systems shall be designed for unattended operation of the Observatory for periods of up to 72 (TBR) hours. Automated ground commands will be used to manage the turn off and turn on of high voltage power supplies for the SAA passages. Automated ground commands also will be used to manage the daily telemetry contacts.

3.1.16 Sky Coverage

GLAST shall obtain full (100%) sky coverage in the Sky Survey Mode, with the minimum point source sensitivity, as specified in the Science Requirements Document.

GLAST shall be capable of acquiring full sky coverage every 3 (TBR) orbits in Sky Survey Mode.

3.1.17 Observing Efficiency

3.1.17.1 Sky Survey Mode

GLAST shall obtain >70% (TBR) observing efficiency in the Sky Survey Mode. The inefficiency is budgeted as follows: approximately 25% to loss of observing time in the South Atlantic Anomaly, approximately 2% data loss in operations, and 1% data loss to identifiable data corruption.

3.1.17.2 Pointed Observation Mode

GLAST shall achieve >50% (TBR) observing efficiency in the Pointed Observation Mode. This mode incurs a maximum inefficiency of 11% due to target switching for Earth occultation. This is in addition to the inefficiencies of the Sky Survey Mode.

3.1.18 System Reliability

System reliability is defined here as the probability that the mission will not suffer a mission ending fault. This pertains to the flight system only, as space-ground communications and the ground system are assured. This requirement guides the selection of components and the implementation of redundancy.

The GLAST system shall achieve an overall reliability of > TBD %. Reliability allocations are as follows:

Launch Vehicle reliability	97 %
Spacecraft reliability	94 %
Primary Instrument reliability	TBD %

3.1.19 System Availability

Availability is the probability that a system will be operational at a particular instant in time, or the percentage of total time that it is operational. This pertains to the loss of observing time that is represented by the loss of data due to fault correction and operational constraints. This requirement guides the fault recovery response times.

Observatory availability	TBD %
MOC and space/ground networks availability	TBD %
IOC availability	TBD %
SOC availability	TBD %

3.1.20 Risk

As a design guideline, GLAST systems shall be designed for low risk of operation. Automatic fault detection and automated notifications shall be provided for quick reactions to system problems.

3.2 Flight System

The flight system is defined as “everything that flies”. This consists of the Launch Vehicle and the Observatory. The Observatory, in turn, consists of the Spacecraft and the Instrument Payload.

3.2.1 Launch Services

GLAST will use U. S. commercial launch services as required for NASA related missions.

3.2.1.1 Launch Vehicle

The launch vehicle shall be the equivalent of a Delta 7920-10 with a 6915 payload attach fitting.

3.2.1.2 Launch Site

The latitude of launch site shall be chosen to provide the required orbital inclination.

3.2.2 Observatory System Requirements

3.2.2.1 Instrument Complement

The GLAST Observatory shall accommodate 1 primary instrument and 1 secondary instrument (TBR).

3.2.2.2 Mass

The Observatory total mass at launch shall be 4500 kg, maximum.

3.2.2.3 Power

Orbit average power for the Observatory shall not exceed 1.2 kW during the operational lifetime of the mission.

3.2.2.4 Data Storage

The Observatory shall provide on–board storage for 36 (TBR) hours of science data accumulated at an orbit average rate of 300 kbps and of observatory housekeeping data at an orbit average rate of 15 kbps (TBR).

3.2.2.5 Stored Commands

The Spacecraft shall provide a stored command capability that will support sequences of pointed observations covering observation periods of up to 4 (TBR) weeks.

3.2.2.6 Pointing Accuracy

The Spacecraft shall provide pointing and control absolute accuracy of less than 2/3 degrees, 1 σ radial.

3.2.2.7 Pointing Knowledge

The Spacecraft shall provide pointing knowledge of less than 10 (TBR) arcsec, 1 σ radial.

3.2.2.8 Position Accuracy

Orbital position of the Observatory shall be known to an accuracy of less than 1 km (TBR) at all times.

3.2.2.9 Repointing

The Spacecraft shall provide a repointing capability that can be enabled and disabled by command.

When enabled, the Spacecraft shall repoint the observatory to transient targets upon notification by the secondary instrument (TBR) of on-board detection of a Gamma-ray Burst, or upon receipt of a ground-generated alert command.

When enabled, the Spacecraft shall repoint the observatory to alternate targets upon stored command in Pointed Observation Mode during Earth occultation.

The Spacecraft shall slew the observatory 90 degrees (TBR) in any direction within 5 (TBR) minutes.

3.2.2.10 Timing

The Spacecraft shall maintain a time code to an accuracy of 10 µs, 1σ.

3.2.2.11 Autonomy

The Spacecraft shall be capable of down-linking science data under control of automated ground commands. The Spacecraft shall perform continual on-board monitoring of temperature and power of its own subsystems and of SI interfaces. The SI shall perform on-board orbit position determination as a backup to automated ground commands that manage SI high voltage power supplies for SAA passages.

3.2.2.12 Safe Mode

The Spacecraft shall implement an autonomous Safe Mode in response to any anomaly in spacecraft subsystems that affects the Spacecraft's ability to remain power positive. In this mode the Observatory shall shed non-essential loads and shall reference its attitude to the sun to maintain sun–pointed solar arrays. The Spacecraft shall remain in this mode until commanded to an operational mode by ground command.

3.2.3 Primary Instrument Requirements

3.2.3.1 Functional Requirements

3.2.3.1.1 Basic Gamma-Ray Measurements

The primary instrument shall measure the direction and energy of gamma-rays in the range of 20 MeV to 300 GeV.

Event data shall be encapsulated in CCSDS packets using one variable-length packet per event.

The SI shall generate stand-alone source packets by including ancillary data in each packet, such as orbit position, observatory attitude, and time.

The SI shall perform on-board orbit position determination as a backup to automated ground commands that manage SI high voltage power supplies for SAA passages.

3.2.3.1.2 Gamma-ray Bursts

The primary instrument shall perform on-board recognition of gamma-ray bursts in real time.

The SI shall generate an alert message that contains the direction of gamma-ray bursts.

The SI shall provide energy measurements of the gamma-ray burst in real time.

3.2.3.1.3 AGN Flare Detection

The primary instrument shall monitor active galactic nuclei over a period of 1 to 4 (TBD) orbits to detect flares in real time. Upon recognition of an AGN flare, the SI shall initiate a message to the ground with time and direction of the flare.

3.2.3.2 Performance Requirements

The SI shall meet the performance requirements that are given in the Science Requirements Document.

3.2.3.2.1 Field of View

For purposes of Observatory pointing, the field of view of the primary instrument shall be a cone of 60 degrees full angle centered on the X-axis of the Observatory.

3.2.3.2.2 Point Source Location

The GLAST primary instrument shall determine point source locations to within 0.5 to 5 arcmin at 1 GeV.

3.2.3.3 Constraints

3.2.3.3.1 Mass

The GLAST primary instrument mass shall be 3000 kg, maximum.

3.2.3.3.2 Power

The GLAST primary instrument orbit average power shall be 650 W, maximum.

3.2.3.3.3 Data Rate

The GLAST primary instrument orbit average data rate shall be 300 kbps, maximum.

3.2.4 Secondary Instrument Requirements

3.2.4.1 Mass

3.2.4.2 Power

3.2.4.3 Data Rate

3.2.4.4 Energy Range

3.2.4.5 Field of View

3.2.4.6 GRB Detection

3.2.4.6.1 Light Curve Threshold

3.2.4.6.2 Direction Determination

3.2.4.6.3 Time Stamp

3.2.4.6.4 Alert Message

3.3 Communications System

The Space Network consists of a system of relay satellites, such as TDRSS, and includes their supporting ground stations. This system is required to provide the following functional support for the GLAST mission.

The bit error rate for the overall system shall not exceed 1 x 10^{-7} (TBR).

3.3.1 Space Network

3.3.1.1 Launch and Early Orbit Support

The Space Network shall provide extended periods of communications and tracking support for the launch event, initial orbit acquisition, and early orbit operations.

3.3.1.2 In-orbit Checkout Support

During the period of in-orbit checkout, the Space Network shall provide extended periods of real-time commanding and telemetry support.

3.3.1.3 Contingency Operations Support

The Space Network shall provide extended periods of communications and tracking support for anomaly resolution during Safe Mode operations.

3.3.1.4 Alert Transmissions

The Space Network shall provide on-demand transmissions of alerts of celestial events to and from the GLAST Observatory and of alerts of Safe Mode from the Observatory.

3.3.1.5 Software Loads

The Space Network shall support uploads of large blocks (1 MB) of software to the GLAST primary Instrument.

3.3.2 Ground Network

The Ground Network in this document is generic and consists of direct link ground stations and their communication links to the Mission Operations Center. These ground stations will be multi-mission stations, and GLAST will be one of several missions supported by them.

3.3.2.1 Ground Station Locations

The latitude and longitude of ground stations for GLAST are TBD.

3.3.2.2 Availability

During early orbit checkout, and on other “infrequent” (TBD) occasions during the mission, the GN stations shall be available for contacts on every orbit for several (TBD) days at a time.

During normal mission operations, the GN stations shall be available for daily contacts on at least 3 (TBR) successive orbits.

3.3.2.3 Reliability

At least 1 (of 2) GN stations shall be available every day of the mission.

3.3.2.4 Automation

Each GLAST GN station shall be capable of operating with an unattended MOC. (This capability is required to support "lights out" operation on weekends.)

3.3.2.5 Link Communications

Each GN station shall be equipped to provide simultaneous S-band and X-band support on the same contact. The GN stations shall provide the communication data rates (TBR) given in Table 3-1.

	S-Band	**X-Band**
Uplink	2 kb/s	-
Downlink Normal Operations Emergency Operations	32 kb/s 4 Mb/s	150 Mb/s

Table 3-1 Communications Data Rates

3.3.2.6 Data Handling

Each GN station shall perform the following data handling functions.

3.3.2.6.1 Capture

The GN station shall capture downlink S-band data and downlink X-band data. This includes demodulation, bit and frame synchronization, and error detection and correction.

3.3.2.6.2 Buffering

The ground station shall buffer the X-band frame data while performing the operations of accounting, merging, and packet recovery and until the MOC confirms that the data have been received.
The GN station shall buffer the S-band data only as long as needed to perform packet recovery.

3.3.2.6.3 Accounting

The GN station shall identify frames that are missing and frames with uncorrectable errors. The ground station shall provide accounting data to the MOC to command selective retransmissions on subsequent contacts to recover any missing or faulty frames/packets.

3.3.2.7 Commanding

The GN station shall uplink commands and data from the MOC for the management of telemetry contacts and for the routine commanding of the GLAST Observatory.

3.3.3 Global Positioning System

GLAST will utilize the services of the Global Positioning System (GPS). The GPS consists of the constellation of GPS satellites in 12-hour orbits and their master control center. No special performance capabilities or permissions are required of this system.

3.3.3.1 Availability

At least 4 GPS satellites will be visible to GLAST at all times.

3.3.3.2 Timekeeping

The Global Positioning System shall provide Universal Coordinated Time continually to the GLAST Observatory with an accuracy of less than 1 μs.

3.3.3.3 Orbit Position Vector

The Global Positioning System shall provide pseudo-range measurements of the GLAST Observatory continually to the Observatory in Earth-Centered, Earth-Fixed coordinates, using the Standard Positioning Service. GPS position measurements shall be accurate to within 100 m.

3.4 Ground System Requirements

Ground system requirements fall into 3 functional areas, the Mission Operations Center (MOC), the Instrument Operations Center (IOC) and the Science Operations Center (SOC) with Guest Observer Facility (GOF). It is expected that the MOC will be a multi-mission operations center, while the other centers are mission unique to GLAST.

3.4.1 Mission Operations Center

The support functions and capabilities that are required of the MOC for the GLAST mission are given in the following paragraphs.

3.4.1.1 Operations Risk

GLAST is an expensive mission with a goal of a ten years of operation. It shall be operated with low risk to the health and safety of the Spacecraft. The operations approach shall provide for the quick identification of any anomalies and the prompt resolution of these anomalies.

3.4.1.2 Planning and Scheduling

The MOC shall plan and schedule the use of the space/ground communication system, including ground stations, and the operation of the Spacecraft. In particular, the MOC will perform the overall management of telemetry contacts. This will include coordinating the GLAST ground stations and commanding the Spacecraft for the downlink of telemetry data, commanding any retransmissions of science data from the Spacecraft, and merging the data sets from different ground stations.

3.4.1.3 Orbit Determination

The MOC shall generate Observatory ephemerides from on-board GPS position and time as received in SC housekeeping data. The MOC shall provide these ephemerides to the direct ground stations for the generation of antenna look angles.

3.4.1.4 SAA Avoidance

The MOC shall generate automated ground commands that turn on and off the SI high voltage power supplies for SAA passages. A 5 degree (TBR) guard band shall be added to the SAA contour below 0 degrees at GLAST altitude.

3.4.1.5 Observatory Commanding

3.4.1.5.1 Observational Commanding

The MOC shall generate the command loads for the Observatory. These command loads will be generated from high-level observing commands that are received from the SOC. Routine commanding will be uplinked via GN station on a daily, weekly, or monthly basis.

3.4.1.5.2 Target of Opportunity Commanding

The MOC shall forward automatically target of opportunity commands that are received from the SOC. These commands are expected to occur on a daily basis and will be uplinked in real time via relay satellite.

3.4.1.5.3 Problem Response Commanding

In response to problem investigation the MOC shall perform troubleshooting and remedial commanding.

3.4.1.5.4 Software Uploads

The MOC will uplink software loads for the SI that are generated by the IOC and coordinated by the SOC. These uploads will be performed occasionally on an as-required basis and will be uplinked via relay satellite. The MOC shall be capable of uploading at least 1 Mbyte of data (such as a software load) within 24 hours.

3.4.1.6 Observatory Health and Safety

The MOC shall maintain the health and safety of the Observatory by monitoring housekeeping telemetry data, investigating anomalies and out-of-limits conditions, and taking remedial action. This includes monitoring any critical health and safety parameters associated with the Instrument. Instrument problems will be analyzed and resolved in cooperation with the IOC. Much of the Observatory health and safety monitoring will be automated.

The MOC shall receive SC housekeeping data from the GN stations. These include both real time data and playback data. The MOC shall process the housekeeping data packets automatically, extracting parameters from the packet, converting DN to EU, applying offsets and scale factors, and comparing those parameters against limits and configuration states. The MOC shall also generate trend lines and monitor them against limits and rates of change, as required.

3.4.1.7 Alerts

The MOC shall receive alerts from the SC via the SN and process them automatically. The MOC shall distinguish GRB alerts from Safe Mode alerts. GRB alerts shall be forwarded to the GCN system nominally within 5 seconds, while Safe Mode alerts shall be forwarded to an on-call MOC person who is responsible for GLAST.

3.4.1.8 Contingency Operations

The MOC shall investigate anomalous operation of the SC. In particular, the MOC shall respond to Safe Mode alerts with predetermined troubleshooting and response procedures.

The MOC shall provide extended support coverage during launch and early orbit operations, during in-orbit checkout and during Spacecraft contingencies.

3.4.1.9 Science Data Acquisition

The MOC shall acquire a nominal 25 Gb science data set from the Observatory on a daily basis during the operational lifetime of the mission and shall complete the delivery of it to the IOC and SOC within 12 hours.

3.4.1.10 Science Data Processing

The MOC shall accept the science and housekeeping packets from the ground and space networks. The MOC shall merge the data packets from multiple GN stations, placing them in time order, removing duplicate data, and identifying any gaps.

3.4.1.11 Data Distribution

The MOC shall forward <u>all</u> data packets to the SOC for archiving. The MOC shall extract SC engineering data for health and safety monitoring in the MOC. The MOC shall send SI engineering and science data to the IOC.

3.4.2 Instrument Operations Center

The IOC is dedicated to GLAST instrument operations and performs all ground operations functions that are instrument specific.

3.4.2.1 Instrument Health and Safety

The IOC shall monitor Instrument housekeeping data for proper operation of the Instrument. Housekeeping data will be converted to engineering units and monitored against limits and configuration states. A configuration log shall be maintained. Anomalies will be detected and analyzed for their safe resolution.

3.4.2.2 Instrument Commanding

The IOC shall generate the data and commands required to configure and calibrate the Instrument in normal operations. These commands shall be routed through the SOC for coordination with observing plans by the SOC. The IOC shall also generate the command procedures to resolve anomalous operation.

3.4.2.3 Instrument Performance Assessment

The IOC shall perform an on-going assessment of the performance of the Instrument. Current performance will be compared against historical performance to detect changes and degradation. Actual performance will be compared against predicted performance to understand any idiosyncrasies and anomalies. The IOC will maintain an analytical performance model of the instrument.

3.4.2.4 Instrument Calibration

The IOC shall analyze instrument calibration data to maintain instrument adjustments and operating parameters and to update calibration parameters that are used in production data processing.

3.4.2.5 Optimize Algorithms

The IOC shall analyze instrument data to determine changes needed to adapt the on board detection algorithms, the ground processing algorithms, and the instrument configuration (thresholds) to the observed data.

The IOC shall generate software for the SOC production processing or software loads to be uplinked to implement any modifications or changes to the instrument algorithms.

3.4.2.6 Validate and Maintain Flight Software

The IOC shall maintain the instrument flight software for the duration of on orbit mission operations. This includes the on orbit validation of the operation of flight software.

3.4.3 Science Operations Center

The SOC is responsible for planning the observations during mission operations, for archiving all data, for performing production data processing to generate high level data products, and to interface with the users of the system and distribute data to them.

3.4.3.1 Observing Plans

3.4.3.1.1 Sky Surveys

The SOC will determine the operations modes and targets of the Observatory, incorporating constraints on the operations, such as Earth occultation and South Atlantic Anomaly restrictions, and integrating configuration commands from the IOC. The SOC shall plan the observing timeline for the mission and shall generate the high-level command scenarios/scripts/macros to implement it. The SOC will forward the high-level command sequence to the MOC for generation of the command upload.

3.4.3.1.2 Targets of Opportunity

The SOC shall receive requests to view targets of opportunity over the internet and over the GCN. Such requests shall be screened by the SOC before being forwarded to the MOC for uplink. The SOC shall generate a high-level command giving celestial sky coordinates and an observing duration for such targets.

3.4.3.1.3 Pointed Observations

The SOC shall generate command scenarios for pointed observations that cover an observing period of 1 to 3 weeks (TBR).

3.4.3.2 Science Data Production Processing

The SOC shall perform the production data processing that is necessary to generate standard high-level data products, such as sky maps and source catalogs. Data processing shall keep pace with the acquisition of observational data on a daily basis. The SOC shall have the capability to process 25 Gb of science data per day. The results of each day's processing shall be available within 6 (TBR) hours from the time of completion of data transmission to the SOC.

3.4.3.3 Archives

The SOC shall generate and maintain an archive for all mission data. The SOC shall format the raw data in FITS format (TBR) for archiving. The SOC shall support archival research during the course of the mission. At the end of mission operations, the SOC will transfer the data to a permanent archive, such as HEASARC, for support of post mission archival research.

3.4.3.4 Data Distribution

The SOC shall provide the standard products and any information required to interpret the data to authorized users.

3.4.3.5 Guest Observer Facility

The SOC shall support guest investigations by evaluating and selecting investigation proposals that are solicited by NASA, by performing the observations required by the selected proposals, by performing the standard data processing of the acquired data, and by providing access to the entire high level data set for the mission.